ARISTARCHUS PLATEAU: A FUTURE ISRU SITE? C.R. Coombs[1], C.C. Allen[2], B.K. Joosten[3], M.F. Johnson[4], [1]College of Charleston, 58 Coming Street, Charleston SC, 29424, USA, cass@loki.cofc.edu, [2]Lockheed-Martin Engineering and Sciences, NASA/JSC, Houston TX 77058, USA, allen@snmail.jsc.nasa.gov, [3]NASA JSC, Code SN2, Houston TX 77058, USA, joosten@snmail.jsc.nasa.go,v, [4]Bridgewater State College, Bridgewater CT, USA, m6johnson@bridgew.edu.

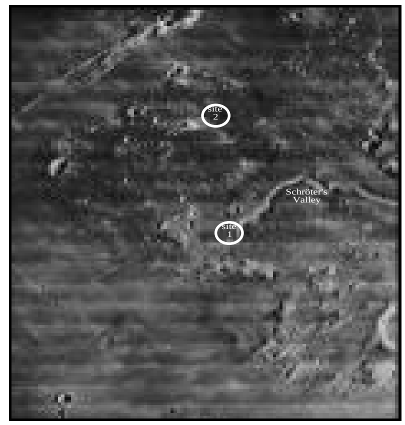
INTRODUCTION

The NASA Strategic Plan calls for opening the space frontier by exploring, using, and enabling the development of space [1]. Within this plan a key goal of the Human Exploration and Development of Space (HEDS) Enterprise is to “Explore and settle the Solar System” [2]. As part of the exploration strategy, NASA has been studying the feasibility of a low-cost human return to the Moon. The currently planned mission has a dual focus on the advancement of lunar science and the use of *in situ* resources. To date, humans venturing into space have relied almost exclusively on equipment and supplies carried from Earth. This strategy is certainly appropriate for operations in Earth orbit, or for stays of a few days on the surface of the Moon. However, the ability to effectively utilize local resources, to “live off the land,” will prove vital for long term habitation of the Moon and planets. This study synthesizes a wide range of data to characterize the Aristarchus Plateau, one of the primary candidate sites for human lunar exploration. Based on this synthesis study, we recommend two sites on the Aristarchus Plateau that will maximize science return and provide a convincing demonstration of the use of *in situ* resources and which may be a viable future lunar base site.

BACKGROUND

The Aristarchus Plateau is located in central northeastern Oceanus Procellarum on the lunar nearside (25°N 52°W). For years the Aristarchus Plateau has been a subject of interest to planetary scientists. It is one of the most geologically diverse regions for its size on the lunar surface. Recognized early in the Apollo days as being unique, it became an early candidate for an Apollo landing when site selection discussions stressed the need for geologic diversity and traverse distance [3]. Its surface is riddled with impact craters and secondary crater chains, volcanic constructs and pyroclastic deposits as well as many sinuous rilles and scarps (Fig. 1). Among the geologic features are a blanket of dark mantling material; the densest concentration of sinuous rilles as well as the Moon's largest lava channel, Schröter's Valley; volcanic vents, sinks or depressions, and domes; mare materials of various ages and colors; one of the freshest large craters; and other large craters in different states of flooding and degradation [4].

Figure 1: Lunar Orbiter IV photograph of the Aristarchus Plateau. The circles denote the suggested landing sites. Each is ~10 km in diameter. North is up.



The dark mantling deposits that cover much of the plateau are of particular interest. These deposits are very smooth, low units that mantle and subdue underlying terrain. The deposits are thought to be composed of microscopic glass spheres. First found as whole and broken green glass beads at Apollo 15, numerous classes of glass beads are now recognized in the returned Apollo sample collection. On the Apollo 17 mission orange glass beads and their quench-crystallized equivalents were identified at Station 4, Shorty Crater. Interpretations of their origin have swayed from vapor condensates to impact melt ejecta to pyroclastic material [e.g.,5 9].

The geologic diversity and large volume of Fe-rich pyroclastic material present at the Aristarchus site make it an ideal target for extracting O_2, H_2, and halogens. Extraction of lunar oxygen for rocket propulsion is a key example of *in situ* resource utilization that will directly support a long-term human presence on the Moon. This is because one of the largest elements in any rocket is the oxygen required to burn the fuel. Nearly 90% of the propellant mass of a liquid hydrogen-liquid oxygen rocket is oxygen. Locally produced oxygen for rocket propulsion promises by far the greatest cost and mass saving of any *in situ* lunar resource [10]. As discussed below, the pyroclastic glass deposits that mantle much of the Aristarchus

Plateau hold considerable promise as a source of such oxygen.

POTENTIAL *IN SITU* RESOURCE UTILIZATION

Over 20 different processes have been proposed for oxygen production on the Moon [11]. One of the simplest and best studied of these processes involves the subsolidus reduction of ferrous iron (Fe^{2+}) in lunar minerals and glass using hydrogen gas. This method of oxygen production is a two-step process. Ferrous iron (as FeO) is first reduced to metal, and oxygen is liberated to form water. The water is then electrolyzed as a second step, with hydrogen recycled to the reactor and oxygen liquefied and stored. Recent experiments on lunar materials and terrestrial analogs allow an assessment of the various proposed feedstocks for lunar oxygen production. Materials that have been proposed and/or tested include ilmenite, basalt, soil, and volcanic glass. As the following discussion illustrates, some reacted better than others.

The first experiments to extract oxygen from lunar material utilized high-titanium basalt 70035. This sample, with an initial iron content of 14.35 wt%, produced from 3.2 to 4.6 wt% oxygen in hydrogen reduction experiments run at temperatures of 900−1050°C. Ilmenite occurs in abundances above 25 wt% in some lunar rocks. This mineral is easily reduced, and oxygen yields of 8−10 wt% may be achievable. However, experiments to date have invariably failed to completely segregate ilmenite from other mineral fragments, so that stoichiometric oxygen yield has not been realized.

Oxygen yields from soils are predictable, based solely on each sample's initial Fe abundance. Iron-poor highland soils yield 1−2 wt% oxygen. Mare soils, especially those high in iron, yield as much as 3.6 wt% oxygen. The dominant Fe-bearing phases in lunar soil are the minerals ilmenite, olivine, pyroxene and impact glass. Each of these phases is a source of oxygen.

The greatest yield, 4.6 wt%, is derived from extremely iron-rich volcanic glass, making it the optimum feedstock for production of lunar oxygen and other volatiles. At least 25 distinct glass compositions have been identified in the Apollo sample collection. The iron- and titanium-rich species, represented by the isochemical black and orange glasses from the Apollo 17 landing site, have demonstrated the highest oxygen yields of any lunar sample, approaching 4.5 wt% [12]. These samples are uniformly fine-grained, offering a feedstock that reacts rapidly and can be used with little or no processing prior to oxygen extraction.

Earth-based data, Apollo orbital photography and Clementine multispectral imagery was used to determine the precise extent and estimate the thickness of one widespread deposit covering the Aristarchus plateau [after 13]. We estimate the local pyroclastic resource reserve at 10−30 km depth with a volume of ~8000 km^3 over a 100 km area.

SUMMARY

In preparation for the Human Lunar Return (HLR) we have selected two potential landing sites on the Aristarchus Plateau (24°N 52°W) for an *in situ* resource utilization (ISRU) demonstration (Fig. 1). Recent planning for return to the Moon indicates that large cost savings can result from using locally produced oxygen, and recent JSC laboratory results indicate that iron-rich pyroclastic dark mantling deposits may be the richest oxygen resource on the Moon. Our earlier work demonstrated that instead of using regolith, bulk lunar pyroclastic deposits are better suited for beneficiation as they are thick (tens of meters), unconsolidated, fine-grained deposits. In addition, the lack of rocks and boulders and the typically flat to gently rolling terrain will facilitate their mining and processing.

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